

Operational Earthquake Forecasting: State of Knowledge and Guidelines for Utilization

**Report of the
INTERNATIONAL COMMISSION ON EARTHQUAKE
FORECASTING FOR CIVIL PROTECTION**

Thomas H. Jordan, chair

International Commission

- **Established by the President of the Council of Ministers of Italy in April, 2009, following the L'Aquila earthquake**
 - Appointed by Dr. Guido Bertolaso, head of Dipartimento della Protezione Civile (DPC)
- **Mandate to the Commission:**
 1. Report on the current state of knowledge of short-term prediction and forecasting of tectonic earthquakes
 2. Indicate guidelines for utilization of possible forerunners of large earthquakes to drive civil protection actions, including the use of probabilistic seismic hazard analysis in the wake of a large earthquake

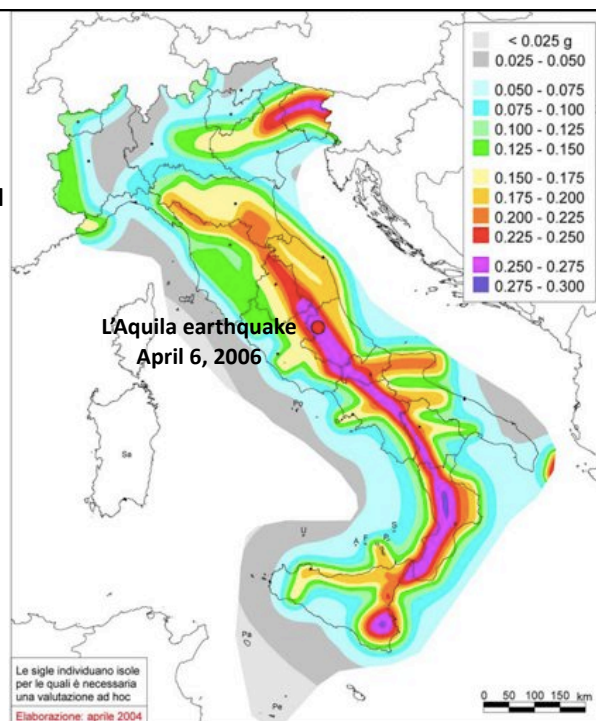
International Commission

- **Thomas H. Jordan, Chair of the Commission**, Director of the Southern California Earthquake Center and Professor, University of Southern California, Los Angeles, USA
- **Yun-Tai Chen**, Professor and Honorary Director, Institute of Geophysics, China Earthquake Administration, Beijing, China
- **Paolo Gasparini, Secretary of the Commission**, Professor of Geophysics, University of Napoli "Federico II", Napoli, Italy
- **Raul Madariaga**, Professor at Department of Earth, Oceans and Atmosphere, Ecole Normale Supérieure, Paris, France
- **Ian Main**, Professor of Seismology and Rock Physics, University of Edinburgh, United Kingdom
- **Warner Marzocchi**, Chief scientist, Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
- **Gerassimos Papadopoulos**, Research Director, Institute of Geodynamics, National Observatory of Athens, Athens, Greece
- **Gennady Sobolev**, Professor and Head Seismological Department, Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia
- **Koshun Yamaoka**, Professor and Director, Research Center for Seismology, Volcanology and Disaster Mitigation, Nagoya University, Nagoya, Japan
- **Jochen Zschau**, Director Department of Physics of the Earth, GFZ, German Research Centers for Geosciences, Potsdam, Germany

2009 L'Aquila Earthquake Sequence

Tectonic context

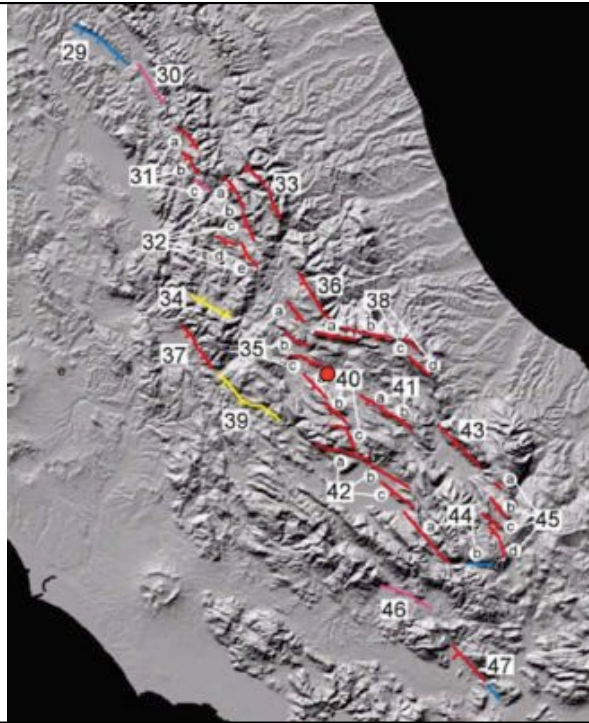
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2009 L'Aquila Earthquake Sequence

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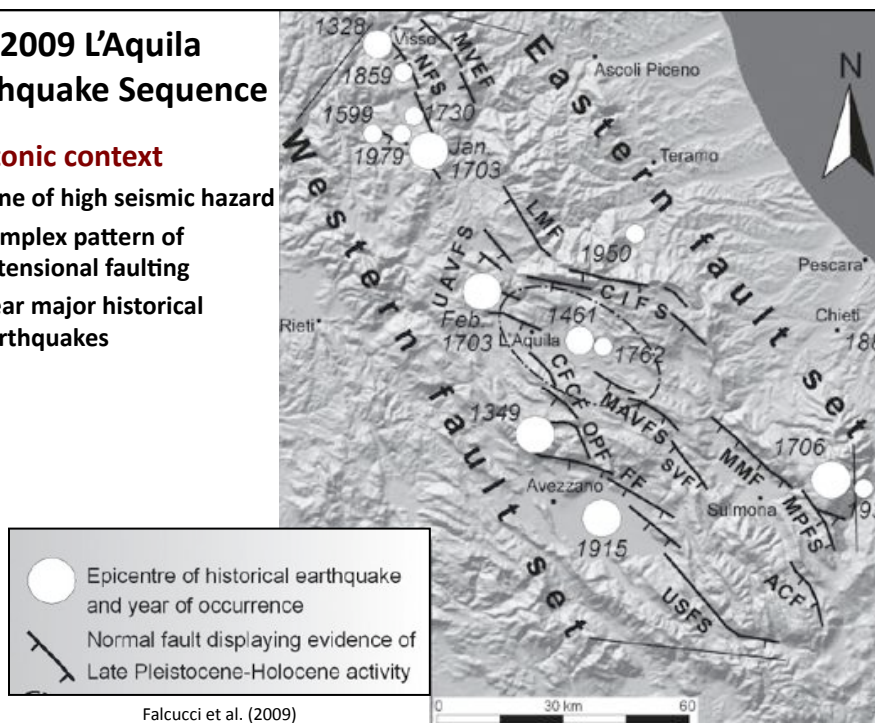
- Zone of high seismic hazard
- Complex pattern of extensional faulting



2009 L'Aquila Earthquake Sequence

Tectonic context

- Zone of high seismic hazard
- Complex pattern of extensional faulting
- Near major historical earthquakes



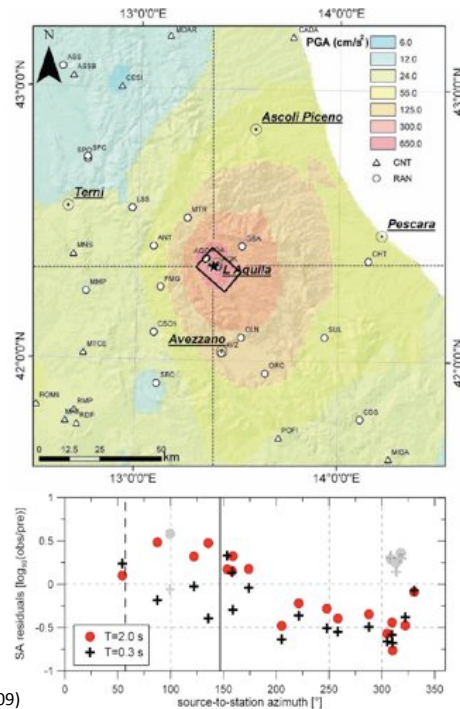
2009 L'Aquila Earthquake Sequence

Tectonic context

- Zone of high seismic hazard
- Complex pattern of extensional faulting
- Near major historical earthquakes

Mainshock of April 6, 3:32 am

- $M_L = 5.8$, $M_W = 6.3$
- $PGA_{max} = 6.46 \text{ m/s}^2$,
 $PGV_{max} = 0.43 \text{ m/s}$ (at AQV)



Ameri et al. (2009)

2009 L'Aquila Earthquake Sequence

Tectonic context

- Zone of high seismic hazard
- Complex pattern of extensional faulting
- Near major historical earthquakes

Mainshock of April 6, 3:32 am

- $M_L = 5.8$, $M_W = 6.3$
- Strong ground motions
- Much destruction
 - 300 killed; 65,000 displaced;
 - 20,000 buildings red-tagged





2009 L'Aquila Earthquake Sequence

Tectonic context

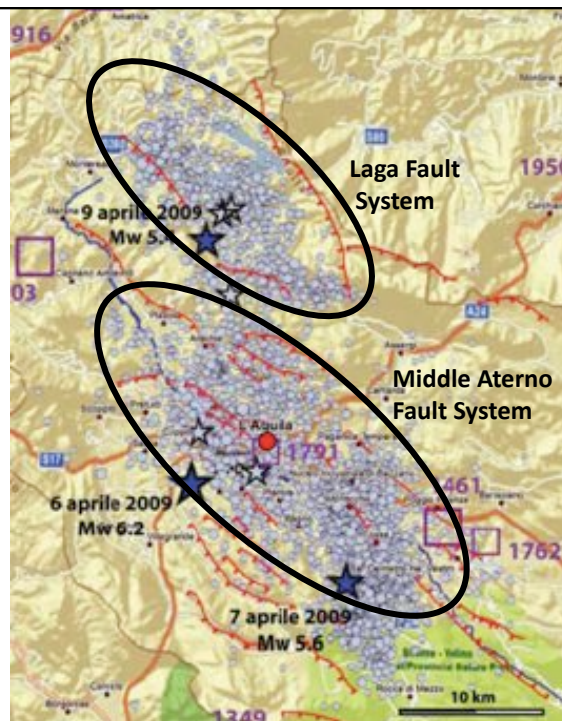
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Complex Sequence

- Two fault zones activated



2009 L'Aquila Earthquake Sequence

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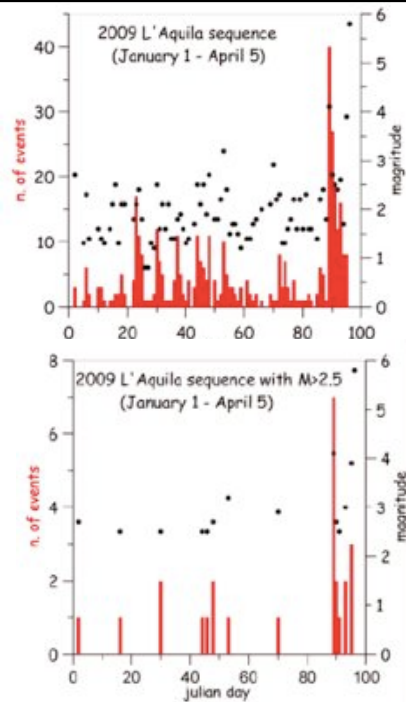
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Complex Sequence

- Two fault zones activated
- Rich foreshock sequence

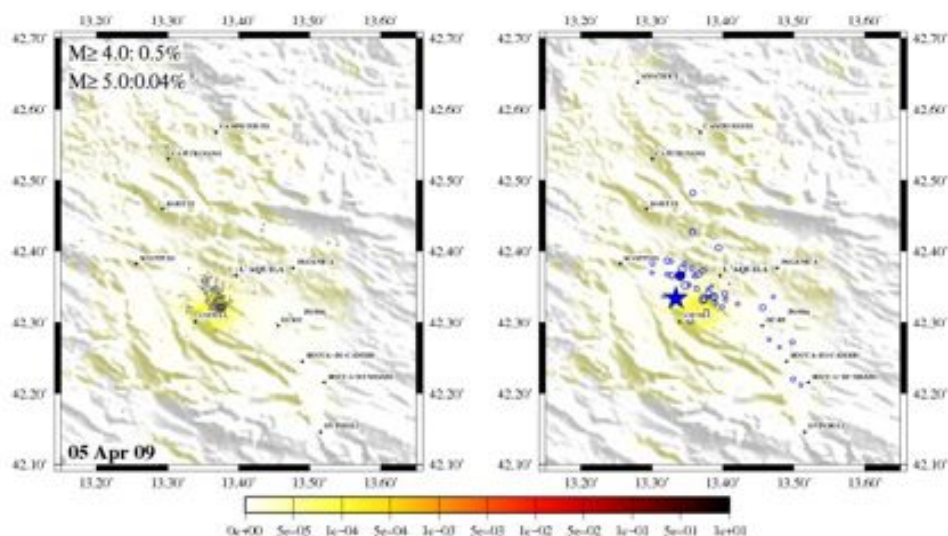


SCEC-VDO Animation of
L'Aquila Earthquake Sequence
Apr 1-12, 2009

Response to the L'Aquila Sequence

- **Feb 18:** Mr. G. Giuliani, a technician at the Gran Sasso National Laboratory, predicts a $M=2-2.5$ earthquake for the next day with epicenter in Roio. Giuliani says "in the last month all the earthquakes were forecasted by using my instruments and methods." No such event occurs.
- **Feb 24:** Frepoli (INGV) states "It is impossible to make earthquake forecast. This seismic swarms is normal in an area like the L'Aquila region."
- **Mar 14:** Selvaggi (INGV) states "A swarm like this in L'Aquila does not increase or decrease the probability for a high magnitude event. In spite of research on the earthquake precursors are performed all over the world, actually earthquake are not predictable."
- **Mar 30:** Sequence intensifies. After a quake located near Sulmona, Giuliani tells the mayor of the town to expect a damaging earthquake within 6-24 hours. Vans mounted with loudspeakers blare warnings to residents to flee. Many people do. An earthquake does not occur in the prediction window
- **Mar 31:** Commissione Grande Rischio issues a statement, "There is no reason to say that the sequence of events of low magnitude can be considered precursory to a strong event." Italian authorities tell Giuliani that he was panicking an already jittery population and they would not allow him to publicize any predictions. Giuliani was denounced for panicking the population.
- **Apr 1:** DPC head Bertolaso requests for quite. De Bernardinis says "Taking into account the scientific knowledge on this seismic swam, we do not expect an increase in the earthquake magnitude."
- **Apr 6:** Mainshock at 3:32 am
- **Apr 7:** INGV issues its first 24-hr aftershock forecast at 8:00 am, about 15 hrs after the mainshock
- *In the aftermath of the L'Aquila earthquake there was considerable public criticism of DPC procedures and controversy about the predictability of the mainshock.*

INGV One-Day Aftershock Forecasts



ICEF Report

- ***Outline of the report***
 - Introduction
 - Science of Earthquake Forecasting and Prediction
 - Status of Operational Earthquake Forecasting
 - Key Findings and Recommendations
- ***Definitions***
 - An *earthquake prediction* is a deterministic statement that a future event will or will not occur in a particular geographic region, time window, and magnitude range.
 - An *earthquake forecast* gives a probability (greater than zero but less than one) that such an event will occur.
 - *Earthquake predictability* is the degree to which the future occurrence of earthquakes can be determined from the observable behavior of earthquake systems.

ICEF Findings & Recommendations

- ***Need for Probabilistic Earthquake Forecasting***
 - Probabilistic earthquake forecasting can convey information about future earthquake occurrence on various time scales, ranging from long term (years to decades) to short term (months or less). Probabilistic forecasting is a rapidly evolving field of earthquake science.
 - ***Recommendation A: DPC should continue to track the scientific evolution of probabilistic earthquake forecasting and deploy the infrastructure and expertise needed to utilize probabilistic information for operational purposes.***

ICEF Findings & Recommendations

- ***Earthquake Monitoring***

- Not all of the high-quality information from seismic networks run by different agencies is currently available to DPC. Strain-rate monitoring and other types of geodetic analysis are also distributed across several agencies that process the data using independent methods.
- ***Recommendation B.1: DPC should coordinate across Italian agencies to improve the flow of data, in particular seismic and geodetic monitoring data, into operational earthquake forecasting.***
- ***Recommendation B.2: Particular emphasis should be placed on real-time processing of seismic data and the timely production of high-quality earthquake catalogs and strain-rate maps.***

ICEF Findings & Recommendations

- ***Research on Earthquake Predictability***

- The Commission has identified no method for the short-term prediction of large earthquakes that has been demonstrated to be both reliable and skillful. In particular, the search for precursors that are diagnostic of an impending earthquake has not yet produced a successful short-term prediction scheme.
- Current knowledge about earthquake precursors is poor, and many intriguing observations have yet to be fully explored. Research on these phenomena will improve the understanding of earthquakes and may produce results with implications for operational earthquake forecasting.
- ***Recommendation C: A basic research program focused on the scientific understanding of earthquakes and earthquake predictability should be part of a balanced national program to develop operational forecasting.***

ICEF Findings & Recommendations

- ***Development of Long-Term Forecasting Models***
 - Time-independent models are currently the most important forecasting tools for civil protection against earthquake damage. Such forecasts are the foundation for the seismic hazard mapping that guides safety provisions of building codes, performance-based seismic design, and other risk-reducing engineering practices, such as retrofitting to correct design flaws in older buildings. Stringent building codes and seismic retrofitting regulations are the most effective measures communities can adopt to ensure seismic safety.
 - ***Recommendation D: DPC should continue its directed research program on development of time-independent and time-dependent forecasting models with the objective of improving long-term seismic hazard maps that are operationally oriented.***

ICEF Findings & Recommendations

- ***Development of Short-Term Forecasting Models***
 - Triggering and clustering models explain many statistical features observed in seismicity catalogs, such as aftershocks, and they can be used to construct forecasts that indicate how earthquake probabilities change over the short term.
 - Properly applied, short-term aftershock forecasts have operational utility. Aftershock forecasting can likely be improved by incorporating more information about main shock deformation patterns and geological settings, such as more detailed descriptions of local fault systems.
 - ***Recommendation E.1: DPC should emphasize the deployment of an operational capability for forecasting aftershocks.***

ICEF Findings & Recommendations

- ***Development of Short-Term Forecasting Models (cont.)***
 - The models of earthquake triggering and clustering used in aftershock forecasting can be more generally applied to short-term earthquake forecasting. Additional information from the retrospective analysis of foreshocks, earthquake swarms, and other aspects of seismicity behavior can be used to improve the estimates of short-term earthquake probabilities.
 - ***Recommendation E.2: DPC should support development of earthquake forecasting methods based on seismicity changes to quantify short-term probability variations.***

ICEF Findings & Recommendations

- ***Verification of Earthquake Forecasting Methods***
 - Forecasting models considered for operational purposes should demonstrate reliability and skill with respect to established reference forecasts, such as long-term, time-independent models.
 - ***Recommendation F1: Forecasting methods intended for operational use should be scientifically tested against the available data for reliability and skill, both retrospectively and prospectively. All operational models should be under continuous prospective testing.***
 - ***Recommendation F2: The international infrastructure being developed to test earthquake forecasting methods prospectively should be used as a tool for verifying the forecasting models for Italy.***

ICEF Findings & Recommendations

- ***Utilization of Earthquake Forecasts***
 - An effective structure for assisting decision-makers is to have an expert panel that convenes on a regular basis to engage in planning and preparation and to interpret the output of forecasting models and any other relevant information. The responsibilities of such a panel include the timely synthesis of information necessary for situation assessments during seismic crises and also in “peacetime.” It also provides a mechanism for the evaluation of *ad hoc* earthquake predictions.
 - ***Recommendation G1: An independent panel of experts should be created to evaluate forecasting methods and interpret their output. This panel should report directly to the head of DPC.***

ICEF Findings & Recommendations

- ***Utilization of Earthquake Forecasts (cont.)***
 - One of the outstanding challenges in the operational use of probabilistic forecasts is in translating them into decision-making in a low-probability environment. Although the value of long-term forecasts for ensuring seismic safety is fairly clear, the interpretation of short-term forecasts is problematic because earthquake probabilities may vary over orders of magnitude, but they typically remain low in an absolute sense.
 - ***Recommendation G2: Quantitative and transparent protocols should be established for decision-making that include mitigation actions with different impacts that would be implemented if certain thresholds in earthquake probability are exceeded.***

ICEF Findings & Recommendations

- ***Public Communication of Earthquake Information***
 - Providing probabilistic forecasts to the public is an important operational capability. Good information keeps the population aware of the current state of hazard, decreases the impact of ungrounded information, and contributes to reducing risk and improving preparedness. The principles of effective public communication have been established by social science research and should be applied in communicating seismic hazard information.
 - ***Recommendation H: DPC, in accordance with social-science principles for effective public communication and in concert with partner organizations, should continuously inform the public about the seismic situation in Italy based on probabilistic forecasting.***

Some of the ICEF recommendations may be useful to NEPEC and CEPEC.

1. USGS and CalEMA should formalize programs for operational earthquake forecasting, advised by NEPEC and CEPEC, respectively.
2. Short-term forecasting models should be developed that are consistent with the long-term NSHMP models.
3. The Uniform California Earthquake Rupture Forecast (UCERF) should be developed in a way that allows for continuous prospective testing.
4. A testing infrastructure appropriate for operational models should be developed within the Collaboratory for the Study of Earthquake Predictability (CSEP).

End

2009 L'Aquila Earthquake Sequence

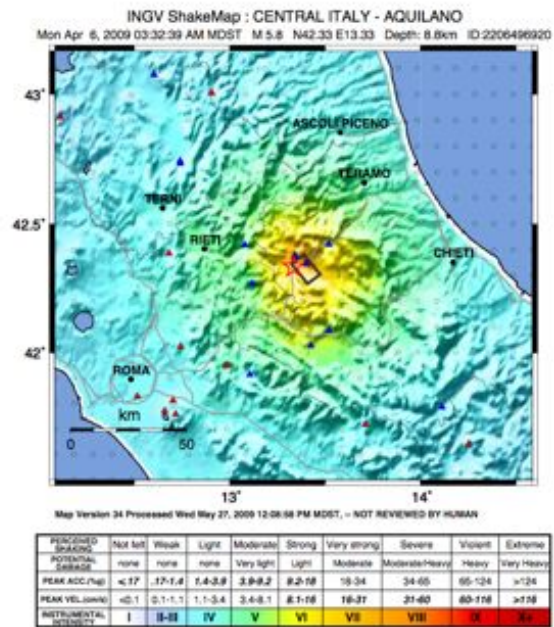
Tectonic context

- Zone of high seismic hazard
- Complex pattern of extensional faulting
- Near major historical earthquakes



2009 L'Aquila Earthquake Sequence

- Occurred in a region of high seismic hazard, near major historical earthquakes



A. Michellini, L. Faenza & V. Lauciani (2009)